Core Scale and Pore Scale Studies of Carbon Dioxide Migration in Saline Formations

Sally M. Benson, Liviu Tomutsa, Dmitriy Silin, Timothy Kneafsey and Ljubinko Miljkovic

Earth Sciences Division, Lawrence Berkeley National Laboratory
Berkeley, California 94720

Introduction

Understanding core scale and pore scale migration of CO_2 will improve our ability to predict storage capacity and determine the effectiveness of solubility and capillary (residual CO_2) trapping. While the theoretical underpinnings of multi-phase flow are well developed for oil and gas production, there are few, if any measurements relevant to CO_2 storage in saline formations. To fill this gap, core scale and pore scale measurements of CO_2 migration in sandstone are being conducted.

Methodology and results

Core scale laboratory experiments have been conducted to measure brine displacement during CO_2 injection into sandstone cores, relative permeability to CO_2 and water, and post-injection capillary trapping as CO_2 migrates subject to buoyancy forces. Cores of Berea Sandstone and the Frio Formation are used for these measurements. X-ray CT scanning is used to quantify the spatial distribution of CO_2 saturation within the cores while flow rates and pressure gradients are measured. An example is shown in Figure 1. These data were collected during injection of CO_2 into a Berea Sandstone. The images are obtained from a 0.5 cm-thick section of the core located 3.5 cm from the inlet. In this figure, the light areas correspond to high CO_2 saturations where the CO_2 has displaced the brine and the dark areas correspond to areas with limited brine displacement. Note the strong influence of small scale heterogeneity on the efficiency of brine displacement by CO_2.

For the Frio Formation and Berea Sandstone cores tested, CO_2 displaces from 25% to 40% of the pore water, depending on the degree of small-scale heterogeneity of the core. As heterogeneity increases, displacement efficiency decreases. Figure 2 provides a calculation of the displacement efficiency in the Berea Sandstone discussed above. As shown, once the “CO_2 front” arrives at the observation point, the saturation of CO_2 increases rapidly to about 35%. After that, the saturation gradually increases to about 40%. This kind of displacement behavior is consistent with multi-phase flow theory for oil and gas reservoirs (Buckley and Leverett, 1942). Water saturated CO_2 is used for these measurements, thus avoiding effects associated with “drying” the core. Additional experiments are being conducted to evaluate how “dry-out” affects displacement efficiency.

To better quantify the influence of small-scale heterogeneity on sweep efficiency, min-permeameter measurements and tracer tests are being used to characterize the flow properties of homogeneous and heterogeneous core samples prior to the CO_2 injection experiments A numerical model of the core scale displacement tests is then used to invert the displacement data to calculate the relative permeability to water and CO_2. These calculated values are then compared to steady state relative permeability measurements.

To gain further insights into the core scale experiments, pore level images of the cores are being obtained at the Advanced Light Source and used as input to pore scale flow models. The pore scale model uses the novel approach of Maximum Inscribed Spheres to calculate capillary pressures and relative permeability to CO_2 and water. Pore scale model calculations are then compared to core scale relative permeability and capillary pressure measurements.

Conclusions

Fundamental understanding of core scale and pore scale multi-phase flow behavior of CO_2-water systems is important for predicting and optimizing storage capacity and trapping mechanisms. Transient and steady state measurements combining flow rates, pressure gradients and X-ray imaging are useful for elucidating these mechanisms. For the cores tested, from 25% to 40% of the water is displaced by CO_2. Experiments also demonstrate that small scale heterogeneity limits displacement efficiency at the core scale. Numerical modeling and pore scale studies provide further insights into multi-phase flow behavior and can be used to up-scale the results of these experiments to understand field-scale behavior.

References

Buckley, S.E. and M.C. Leverett, 1942: Mechanisms of Fluid Displacement in Sands, AIME, 146, 107.

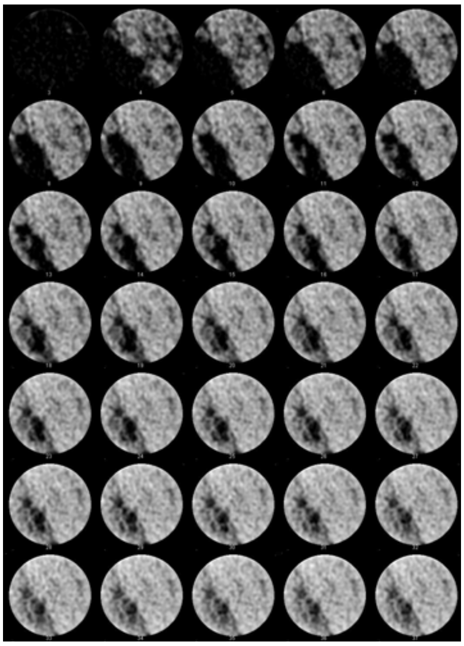

Figure 1. Photomontage showing X-ray CT images collected during a CO_2 core flood of a Berea Sandstone. The montage shows the change in CO_2 saturation as it replaces the brine. The scale is from 0-60% but the maximum CO_2 saturation is only 45%. Note the strong influence of heterogeneity on the displacement efficiency.

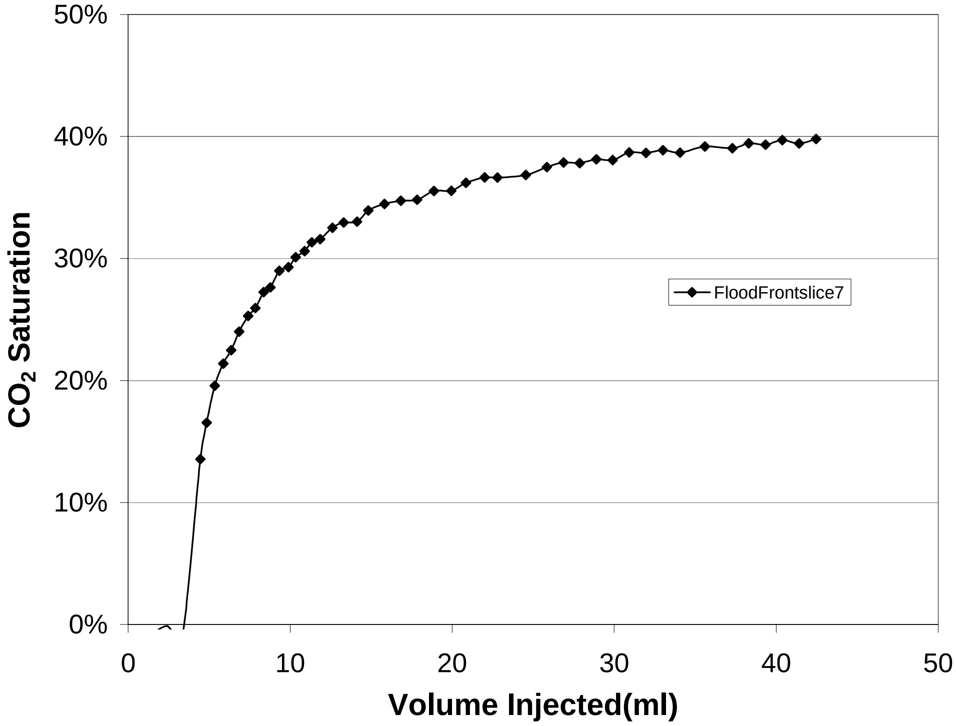

Figure 2. Data from a CO_2 core flood experiment using Berea Sandstone. The permeability of the core is about 700 md. These data are collected from a 0.5 cm-thick cross section located 3.5 cm from the inlet of the core. Carbon dioxide saturations are calculated by averaging X-Ray CT scanning data from the cross-sections shown in Figure 1. Water saturated CO_2 is used in these experiment to avoid complications associated with drying.